Chapter 2
An Assessment of Brazilian Government Initiatives and Policies for the Promotion of Biofuels Through Research, Commercialization, and Private Investment Support

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Abstract This chapter describes some of the scientific and technological achievements that have contributed to develop sugarcane bioenergy as a major contributor to the Brazilian energy matrix. Today, modern bioenergy plays a key role in the Brazilian economy, with 18 % of Brazilian energy usage coming from sugarcane, with ethanol used as fuel and bagasse to generate electricity. This chapter also discusses the Brazilian biodiesel opportunities and biofuels for aviation, which hold promise for the future. The long-term role played by the Brazilian government in promoting biofuels is considered as a key factor to success, particularly with sugarcane ethanol. Government-funded research agencies have played a strategic role in consolidating knowledge and human capacity to maintain leadership in the bioenergy sector. Brazil presents exceptional conditions to expand bioenergy industry (ethanol, biodiesel and biofuels for aviation) and also bioelectricity and green chemistry. To this end it is necessary to create conditions

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for the increase of the private R&D expenditures, as well as governmental actions to train human resources in the area of bioenergy. With new research centers, graduate programs have the potential to contribute to increasing competence at all stages of bioenergy development.

2.1 Introduction

By the end of the nineteenth century, the Brazilian energy matrix was dominated by traditional bioenergy such as the extraction of firewood. In the early twentieth century, use of hydroelectricity and fossil fuels (coal and oil) had gained prominence, imparting complexity to the Brazilian energy matrix. However, even before the end of the Second World War, oil began to dominate the transportation energy sector and hydroelectricity also gained importance. Nevertheless, both traditional (firewood and charcoal) and modern (ethanol and bagasse) forms of bioenergy have remained important. The importance of wood fuel, however, has diminished in the energy matrix, while the use of sugarcane for energy purposes has gained momentum, especially since 1975 (Guerra and Cortez 1992). Today, modern bioenergy plays a key role in the Brazilian economy, with 18 % of Brazilian energy usage coming from sugarcane, with ethanol used as fuel and bagasse to generate electricity.

In this chapter, the major scientific and technological achievements that have contributed to the rising prominence of sugarcane as a bioenergy in the Brazilian energy matrix are presented. This chapter also presents the Brazilian biodiesel market and biofuels for aviation, which hold promise for the future. In this paper, biofuel is defined as a bio-based liquid fuel, but the definition could be extended to include solid biofuels, such as wood and eucalyptus. However, because Brazil is experiencing an upsurge in the use of modern biofuels such as bioethanol and biodiesel, this chapter will be confined to the limited definition.

2.2 Sugarcane Ethanol in Brazil

Brazilian research on sugarcane ethanol as an automotive fuel began in the 1920s with studies conducted by the National Institute of Technology (INT). The addition of ethanol to imported gasoline was mandated by law in Brasil (1931). In 1933, the Brazilian Institute for Sugar and Alcohol (IAA) was created because of a developing crisis in the sugar sector over the use of sugarcane for ethanol. The IAA's focus was to help sugarcane producers while also reducing the consumption of imported gasoline. In 1938, Law No. 737 was passed, requiring the compulsory addition of sugarcane ethanol to all gasoline in Brazil. This law remains in effect even today, with different percentages of ethanol added depending on economic constraints (Fig. 2.1).

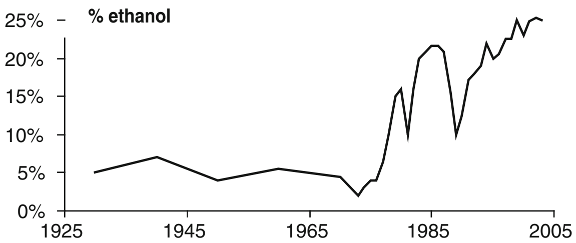
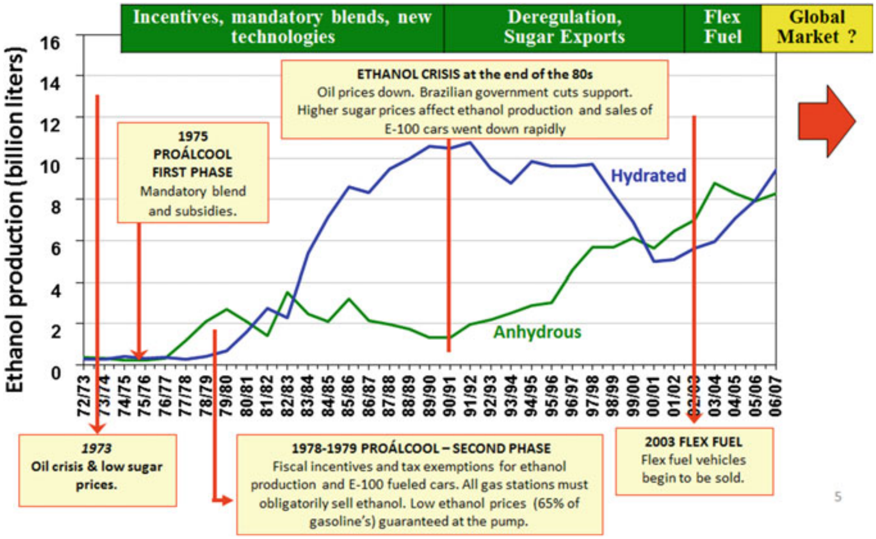


Fig. 2.1 Average ethanol content in the gasoline in Brazil between 1925 and 2005 (Nogueira 2008)



ETHANOL CRISIS at the end of the 80s
Oil prices down. Brazilian government cuts support. Higher sugar prices affect ethanol production and sales of E-100 cars went down rapidly

1975 PROÁLCOOL FIRST PHASE
Mandatory blend and subsidies.

1973 **Oil crisis & low sugar prices.**

1978-1979 PROÁLCOOL – SECOND PHASE
Fiscal incentives and tax exemptions for ethanol production and E-100 fueled cars. All gas stations must obligatorily sell ethanol. Low ethanol prices (65% of gasoline's) guaranteed at the pump.

2003 FLEX FUEL
Flex fuel vehicles begin to be sold.

Fig. 2.2 Phases of Proálcool, 1972–2007 (Datagro 2006; elaborated by ICONE and UNICA)

The first oil crisis in 1973 seriously hurt the Brazilian economy. At that time, the country imported nearly 80 % of its oil, which represented approximately 50 % of total imports. An immediate solution was required to reduce Brazil's dependence on oil. The newly elected President, Ernesto Geisel, who was the former president of Petrobras, enacted a number of measures for the energy sector. On November 14th, 1975, by Decree No. 76.593, the Brazilian government created the National Alcohol Program, also known as "Proálcool."

The Proálcool program has had varying levels of success and failure (Fig. 2.2). Financed by subsidies and liberalization policies, the program has survived changes in regimes (from military to democratic), considerable variations in the price of oil and sugar, and economic and political crises over the past 38 years. The most critical period occurred in the second half of the 1980s, when the ethanol car (E100) accounted for 90 % of total sales of new vehicles in the country. In 1989, ethanol production did not match the domestic demand, primarily because of a lack of planning. Many consumers felt aggrieved and lost confidence in the ethanol car, which dramatically reduced the sales to almost zero in the following years.

The 1990s were marked by a restructuring of the sugar-ethanol sector through gradual deregulation, which allowed Brazil to become a major exporter of sugar. The automotive industry had already begun favoring the sale of cars running on gasoline-ethanol blends (ranging from E20 to E25). With a growing fleet, domestically consumed ethanol was more anhydrous than hydrous, and the demand for both types of ethanol made the total demand for ethanol more or less constant.

By the late 1990s, many consumers had tried using different percentage blends of ethanol and gasoline, popularly known as a “cocktail.”

In the twenty-first century, the rising price of oil has given sugarcane ethanol a new impetus in Brazil. The automotive industry realized that consumers want a vehicle with a flexible engine that would work with any proportion of ethanol in the fuel mixture. The consumer does not want to be at the mercy of price fluctuations, which are common today during the sugarcane inter-harvest period, or be held hostage to a fuel that could be depleted and thus devalue their assets (cars). Concurrently, flex-fuel vehicles (FFV) models were being launched in the U.S., and in 2002, the Ford Fiesta was introduced in Brazil. In 2003, Volkswagen launched the GOL as their first Brazilian flex-fuel vehicle.

The “lambda probe,” a sensor developed by Bosch and Magneti Marelli (MM) to identify blends of fuel, constituted a considerable qualitative development for Brazilian flex engines operating in bi-fuel vehicles. Today, approximately 90 % of the new cars sold in Brazil are flex-fuel vehicles that allow the consumer to select between fuel types, offering greater protection against the fluctuating prices of ethanol and gasoline.

In Brazil, the successful use of sugarcane ethanol was the result of a learning trajectory based primarily on incremental innovations (Furtado et al. 2011). Copersucar (1989), Leite (1990), Magalhães et al. (1991), Moreira and Goldemberg (1999), Moraes (1999), BNDES (2008), Cortez-Coord (2010) Souza and Macedo (2010) and Rosillo-Calle et al. (1998, 2000) describe in detail the history of Proálcool and how Brazil created this internationally recognized success story.

2.2.1 Sugarcane Agricultural Research

Brazil became the world leader in the production and use of sugarcane-derived fuel ethanol and thanks to a successful combination of long-term actions of the government and private sector, including important agronomic research activities. When the National Alcohol Program was implemented in 1975, Brazil was already a major producer of sugarcane (the second largest after India), milling approximately 100 million TC/year. However, the production of fuel ethanol was modest, at approximately 600 million liters per year.

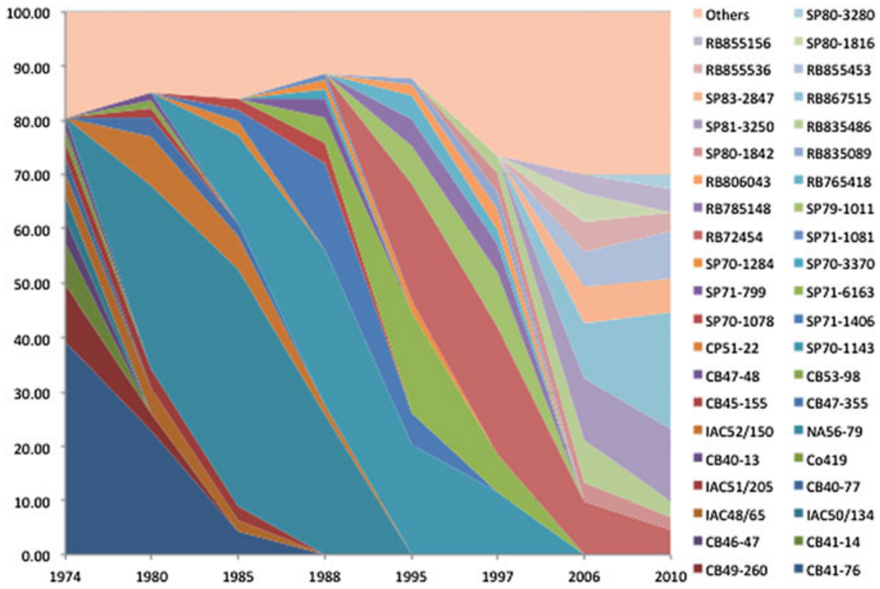


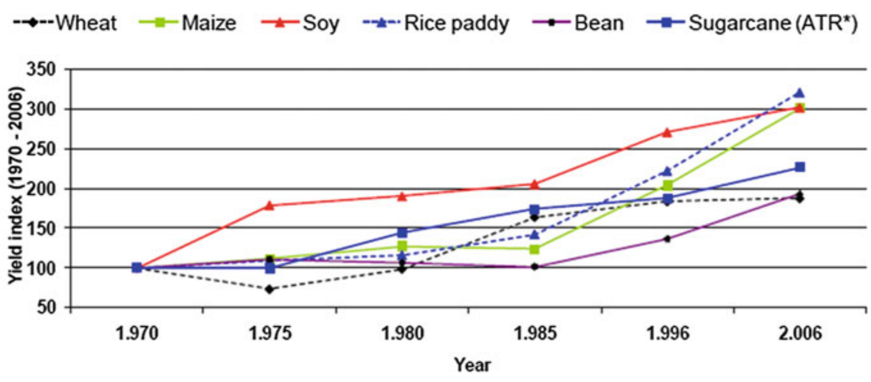
Fig. 2.3 Diversification of commercial sugarcane varieties from 1984 to 2010 in Brazil (*Source* Costa et al. 2011)

Important research centers were also studying sugarcane, including the Agronomic Institute of Campinas (IAC), which had started its breeding program in 1933 and collaborated with the emerging sugar industry in the State of São Paulo to generate important information in the areas of plant nutrition and agricultural practices, forming the basis of existing technologies (IAC and IACSP), and the IAA breeding program of Campos, RJ Station, which was responsible for the CB varieties of sugarcane.

In the early 1970s, the National Program for Genetic Improvement of Sugarcane (Planalsucar) was created by the Brazilian federal government and the Copersucar breeding program (SP varieties) was created with the funds from the private sector.

Until 1975, Brazil had depended on a few sugarcane varieties (Fig. 2.3), including the predominant variety NA5679 from Argentina. However, Planalsucar played an important role in preparing researchers to experiment with sugarcane varieties and creating a sugarcane "genetic bank" in Alagoas, northeast Brazil. New findings emerged in soils, herbicides, diseases, and biological control of sugarcane pests. After the IAA disbanded, Planalsucar resumed its activities in 1990. Its researchers, who were reorganized within federal universities, created the Institutional Network for the Sugar and Alcohol Segment Development (RIDESA) to continue its research and discovery on sugarcane. RIDESA consists of ten federal universities (UFPR, UFSCar, UFV, UFRRJ, UFS, UFAL, UFRPE, UFMT, UFG, and UFPI), has 34 stations, and is responsible for RB varieties of sugarcane.

In the private sector, the State of São Paulo's Sugarcane, Sugar & Alcohol Producers Cooperative—Copersucar was created in 1978, forming the Copersucar



* ATR: Total Recoverable Sugars

Fig. 2.4 Increased yield per hectare for selected Brazilian crops (1970–2006) (Elaborated by M.P. Cunha (CTBE) using data from Brazilian Agricultural Census (IBGE) and from the Brazilian Agroenergy Yearbook 2009)

Technology Center (CTC). After 2004, the CTC was renamed as the Center for Sugarcane Technology and then the Sugarcane Research Center (http://www.ctcanavieira.com.br/). The CTC has played a key role in technology transfer for both the agricultural and industrial sectors. The CTC produced significant advances in agricultural management and in areas such as agricultural mechanization, microbiology fermentation, energy and water conservation, and application of vinasse and filter cake (Burnquist and Landell 2005).

The CTC was established to conduct research and develop new technologies for application in agricultural activities, logistics and industrial sectors, and to create new varieties of sugarcane, with the technology provisioned to cooperative mills. The CTC is responsible for varieties that make up approximately 60 % of the crops of cooperative units and 45 % of the crops of other producers.

The breeding program of the IAC Sugar Cane Program was reorganized in 1994 by the Cane Center of Ribeirão Preto, which has 128 research units operating in 12 states in Brazil that are committed to the integration of science and technology. Some of the contributions of the Cane Center were highlighted by Dinardo-Miranda et al. 2008. This program has the support of APTA units in the cities of Piracicaba, Jaú, Mococa, Pindorama, Assis and Adamantina, and breeding farms in Goianésia (GO) and Luis Eduardo Magalhães (BA).

There are currently four active sugarcane programs in Brazil: IAC, CTC, RIDESA, and Canavialis. The success of the breeding programs is evident from the evolution of sugarcane agricultural productivity in Brazil (Fig. 2.4). Other crops such as corn have shown a remarkable increase in agricultural productivity in recent decades; however, the agro-industrial yield of sugarcane ethanol is approximately 7,000 L/ha.year in Brazil whereas the yield of ethanol from corn is approximately 3,500 L/ha.year in the U.S. Although important progress has been made in developing new cane varieties in Brazil, more research is required, particularly in developing areas where sugarcane is expanding, such as Central Brazil.

2.2.1.1 Other Crops for Ethanol Production

When the Proálcool program was first implemented, the possibility of using other raw materials, such as cassava and sorghum, in the production of ethanol was considered. Production of biodiesel is experiencing a similar growth pattern, including encouraging different cultures, decentralizing production, and giving access to small producers. Initiatives of the Brazilian Ministry of Science and Technology/Secretary of Industrial Technology (MIC/STI) (1980) included designing a mini-distillery to produce 10,000 L/day of cassava alcohol and experiments with EMBRAPA to create an SP model using small-scale diffusers instead of mills and operating with sorghum and sugarcane (Figueiredo et al. 1984). Another important project was led by Petrobras in Curvelo, MG, in 1978, who attempted to implement a cassava ethanol distillery that was developed by INT (Motoyama 2004). The project failed primarily because of agronomic difficulties related to large-scale cassava production. Many of the problems associated with alternative feedstocks are related to a lack of long-term research.

2.2.2 *Other Agricultural Issues in Ethanol Production*

Numerous researchers and Brazilian institutions have played an important role in the development of sustainable sugarcane ethanol, with significant contributions to sugarcane ethanol production originating in Brazilian universities and research centers. The sections below include some of the most important contributions.

2.2.2.1 The End of Sugarcane Burning

Sugarcane burning prior to harvesting is a major environmental problem that pollutes the air and increases respiratory diseases in winter. In September 2002, the legislature of the State of São Paulo passed legislation mandating the gradual reduction of sugarcane burning in São Paulo until 2017: State Law No. 11.241, of 19 September, 2002, shown in Fig. 2.5. “Raw” sugarcane harvesting (without burning) is now practiced in more than 80 % of the harvested areas in São Paulo, which grows over 50 % of Brazil’s sugarcane. Raw cane harvesting is expected to reach 100 % of harvested areas in São Paulo State as mandated by the law. However, the harvest of sugarcane without burning introduced a new technological challenge: mechanically and economically harvesting the entire cane (stalks and straw) without compacting the soil, consuming high amounts of fuel, losing sugarcane, damaging the stumps, and introducing too many impurities to the product.

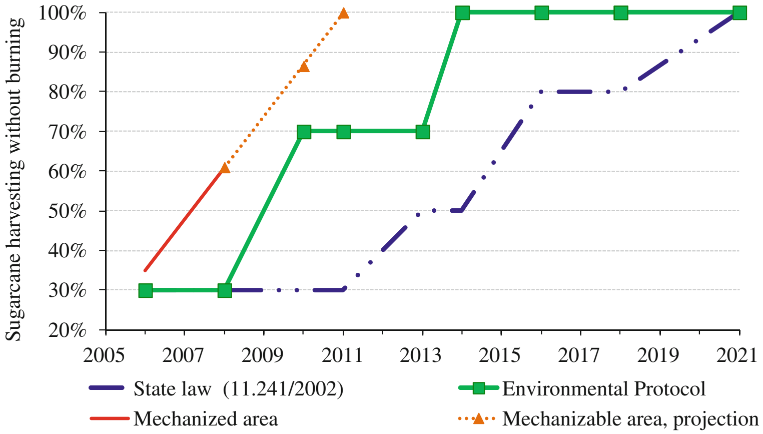


Fig. 2.5 Evolution of the cessation of sugarcane burning and sugarcane harvesting mechanization in the State of São Paulo from 2001 to 2021 (adapted of Macedo 2007)

The CTBE is developing a mechanization approach for sugarcane harvesting (Braunbeck et al. 2005) called a "Controlled Traffic Structure (ETC)" which is specifically designed for low impact mechanization and will introduce no-till farming and precision agriculture for growing sugarcane. (http://www.bioetanol.org.br/interna/index.php?chave=baixoimpacto).

Cane harvesting without burning also introduces the problem of eliminating the cane trash. Burning sugarcane eliminates trash, transforming it into emissions and ash. However, when sugarcane is harvested without burning, left behind trash (composed primarily of leaves and tops) makes the harvesting process less efficient. Significant amounts of sugarcane trash left on the fields confers a degree of agronomical benefit, such as a reduction of soil erosion and moisture loss; however, certain agricultural practices must be changed to manage soil pests that are attracted to the trash. Agronomists recommend that no more than 50 % of the trash be removed from the field, preferably simultaneous with the harvesting process to keep weeds under control. Although the trash material (primarily fibers) may represent an opportunity for generating electricity or second-generation ethanol, there are not enough incentives to make use of the trash economically viable.

2.2.2.2 Recycling Vinasse as Fertilizer (Fertirrigation Technology)

In the early years of Proálcool, vinasse was identified as a major environmental contaminant because it has a high organic load and was commonly disposed of in waterways. An Esalq-USP research group studied vinasse application on the ground, which eventually became a routine practice (Gloria 1975, 1976). Subsequently, the CTC developed more the fertirrigation technology. Today, applying vinasse to the ground helps the sugarcane industry save significant amounts of potassium (Copersucar 1978, 1980; Freire and Cortez 2000 and Fredo et al. 2008).

In addition, Cetesb regulation controls the inappropriate use of vinasse in fertirrigation to prevent groundwater contamination. This standard establishes criteria for calculating the maximum amount of vinasse to be used depending on soil-type and other parameters (*Vinhaça–Critérios e Procedimentos para Aplicação no Solo Agrícola P4.231* Dez/2006 http://www.cetesb.sp.gov.br/tecnologia/camaras/P4_231.Pdf). Although fertirrigation technology represents a good solution in most cases, a reduction is still required in the volume of produced vinasse and the GHG emissions potential.

2.2.3 The Brazilian Industrial Model for Ethanol Production

2.2.3.1 Scale and Model of Ethanol Production in Brazil

When the Proálcool program was first established, the government proposed that a "standard distillery" (capacity of 120,000 L of alcohol/day) be used for production of ethanol. This plant size, now considered too small, was challenged by many researchers who believed that smaller units would favor small-scale production and increase social benefits. The MIC/STI (1981) proposed production models based on micro-distilleries. A research group from USP—São Carlos proposed a model based on "integrated mini-ethanol plants" that was capable of producing 20,000 L of ethanol/day and could, in theory, become a "more social" version of the ethanol program (Corsini 1992). At the time, there were several companies selling units of up to 1,000 L/day, but the small-scale distilleries never achieved the levels of productivity, quality, and economic viability of the large plants. At present, a standard plant has a production capacity of approximately 1 million liters of ethanol/day, although the largest plants in Brazil can produce 4 times that amount.

2.2.3.2 The Brazilian Model of Simultaneous Production of Sugar and Ethanol

The creation of what is known as the "Brazilian model" of simultaneous production of sugar and ethanol was the result of the combined efforts of several researchers: José Paulo Stupiello, Esalq—USP, who contributed to sugar production technology; Young Park, UNICAMP, who contributed to the microbiology of ethanol and fundamental studies on fermentation using sugarcane and other raw materials; and Carlos Vaz Rossell and Jaime Finguerut, CTC, who contributed to optimizing and building the concept of a "flex plant" (Copersucar 1990). These efforts resulted in significant advancements in the ethanol industry, as evidenced by the reduction in fermentation time.

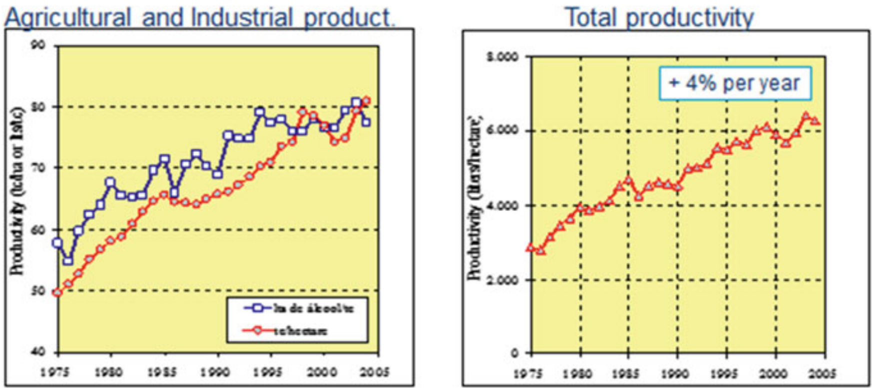


Fig. 2.6 Agro-industrial productivity evolution of sugarcane ethanol through R&D from 1975 to 2005 (*Source* Brito 2012)

These contributions substantially improved ethanol's agro-industrial productivity, which is an indicator based on improvements in agricultural and industrial productivity (Fig. 2.6).

2.3 Development of Ethanol and Flex Fuel Engines in Brazil

One of the first publications on the subject of ethanol and flex fuel engines was the book "Internal combustion engines and ethanol engines," published in 1937 by Eduardo Sabino de Oliveira from the IAA. Much later, Urbano Ernesto Stumpf (CTA) contributed important research on the study of engines fueled by alcohol and received patent #PI8106855-7 for an "alcohol-specific carburetor" on 23/10/1981 (O'Donnell 2009). Another important contribution was made by Romeo Corsini (USP—São Carlos), who received a patent (#PI8402740-1) for the "MAV—pre-evaporized alcohol engine." Additional recognition should be given to the work of Fernando Barata de Paula Pinto of Maxion International Motors, who helped to develop alcohol engines and flex fuel engines. Francisco Nigro (IPT) and Henry Joseph Jr. (ANFAVEA and Volkswagen) helped to develop the alcohol engine and flex-fuel ethanol. Although Brazil has achieved important success in using ethanol fuel, there are still significant challenges to overcome in the design of the engine, which must undergo major changes for use with hybrid engines. Figure 2.7 shows the irregular ethanol vehicle production in Brazil since 1979.

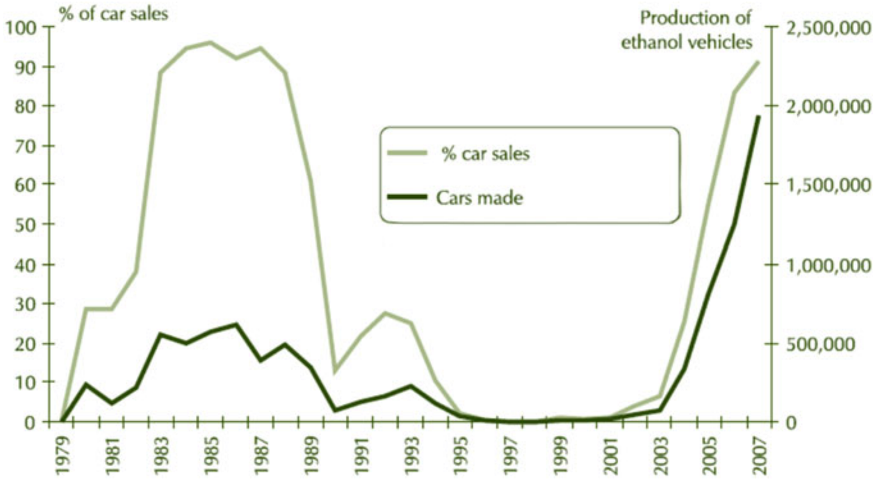


Fig. 2.7 Production and sales of ethanol-based automobiles in Brazil (BNDES 2008)

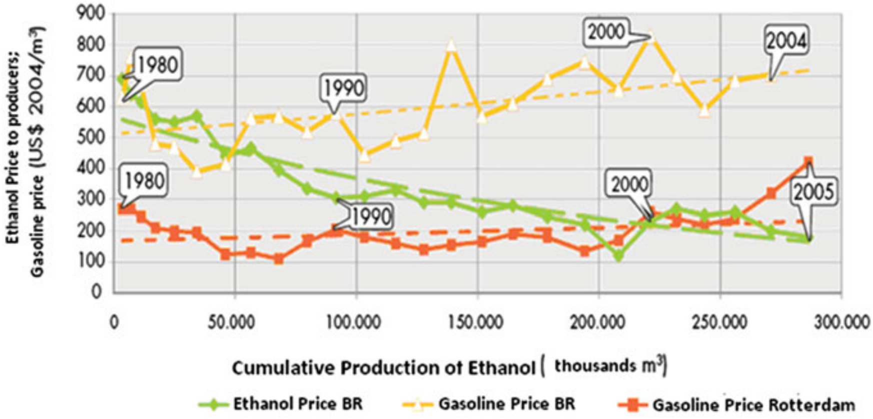


Fig. 2.8 Sugarcane ethanol learning curve (Goldemberg et al. 2008)

2.4 Sustainability of Sugarcane Ethanol

The work of Silva et al. (1978) is also worth mentioning because it is considered as a reference publication on Proálcool and should be recognized as one of the first to address energy balance in the production of ethanol for different crops (Nogueira 1987).

A learning curve proposed by Goldemberg et al. (2004) and collaborators illustrates how production costs have decreased as the quantity of ethanol has increased (Fig. 2.8).

Several research institutions have made significant contributions in the area of sustainability (Camargo 1990), including the IPT (Bonomi 2004), CETESB (Technical Standard P4.231/2006) and INT (STI/INT 1976). Studies have been performed on the digestion of vinasse; however, the digestion of vinasse has not been incorporated in ethanol distilleries, with the exception of Usina São Martinho. UNICA also published an important contribution that summarized 12 major themes related to ethanol's energy and environmental sustainability (Macedo-Coord 2005). Several current ethanol research groups have concentrated their efforts in trying to understand the socioeconomic and environmental issues arising from sugarcane ethanol production and use (Macedo et al. 2008).

2.4.1 Impacts of Ethanol Fuel Use on Population Health

The academic community has made important contributions to public health issues related to vehicle emissions. Saldiva from the Laboratory of Pathology—Medicine (USP) studied the impact of ethanol fuel usage and the emissions generated by more than 5–6 million cars (mostly flex-fuel) in the city of São Paulo. According to Saldiva, replacing gasoline with ethanol fuel is an important public policy measure that improves the health of populations living in large cities because ethanol fuel helps to alleviate air pollution (UNICA 2009 and http://www.worldcat.org/identities/lccn-no00-41804).

2.4.2 Social Science Research Related to Sugarcane Ethanol

Research on the social and economic impacts of sugarcane ethanol production and use in Brazil has received substantial attention from researchers. Presented below is a list of important contributions in ethanol production and use.

Balsadi and Borin (2006) applied a "Quality Index" based on earnings, level of formality, education, and other forms of economic support to analyze the sugarcane sector with regard to improvement of employment (both in quantity and quality) and concluded that each of these indicators had shown significant improvement over the period studied, from 1990 to 2002.

Moraes (2007, 2009, and 2011a , b) analyzed several aspects of the sugarcane, sugar, and ethanol labor markets in Brazil, including the evolution of socioeconomic indicators (number of workers, wages, work formalization, and conditions, etc.), sugarcane worker migration, and income determinants for workers in sugarcane plantations and in the sugar and ethanol industries (influence of education, labor unions, region, etc.).

Moraes (2011a) analyzed the social externalities of fuels and compared indicators between the sugarcane-ethanol and oil industries. They also estimated the socioeconomic impacts of substituting gasoline with ethanol.

Chagas et al. (2011) analyzed the effects of increased sugarcane production on municipal revenues in the State of Sao Paulo. Their results suggested that there is a significant and substantial increase in revenue with increased shares of sugarcane in the municipal agricultural output.

Hofmann (2006) analyzed the effects of increased ethanol production on the reduction of poverty in Brazil. The effects of increased ethanol production on the country's food security is primarily positive. Lack of food security in Brazil is strongly associated with poverty, which should diminish with the increase in employment and income that results from an expansion of sugarcane agribusiness, thus, compensating for the negative effect of eventual increases in food prices.

Martinelli et al. (2011) compared development indicators in municipalities of the State of São Paulo. A series of indices were used, including the following: the human development index (HDI) of the UN, an HDI index based on São Paulo's social responsibility index (SRI) and the Rio de Janeiro municipal development index (MDI). The results showed that the HDI, SRI, and MDI for cattle municipalities were significantly lower than for all the other categories, with the highest results in municipalities with both sugarcane and processing mills, which were higher than nonrural municipalities.

Assato and Moraes (2011) analyzed the socioeconomic impacts of the expansion of the sugarcane sector in two municipalities of Mato Grosso do Sul State and found an increase in aggregate income and improvements in education because of educational programs installed after the expansion of the sugarcane industry.

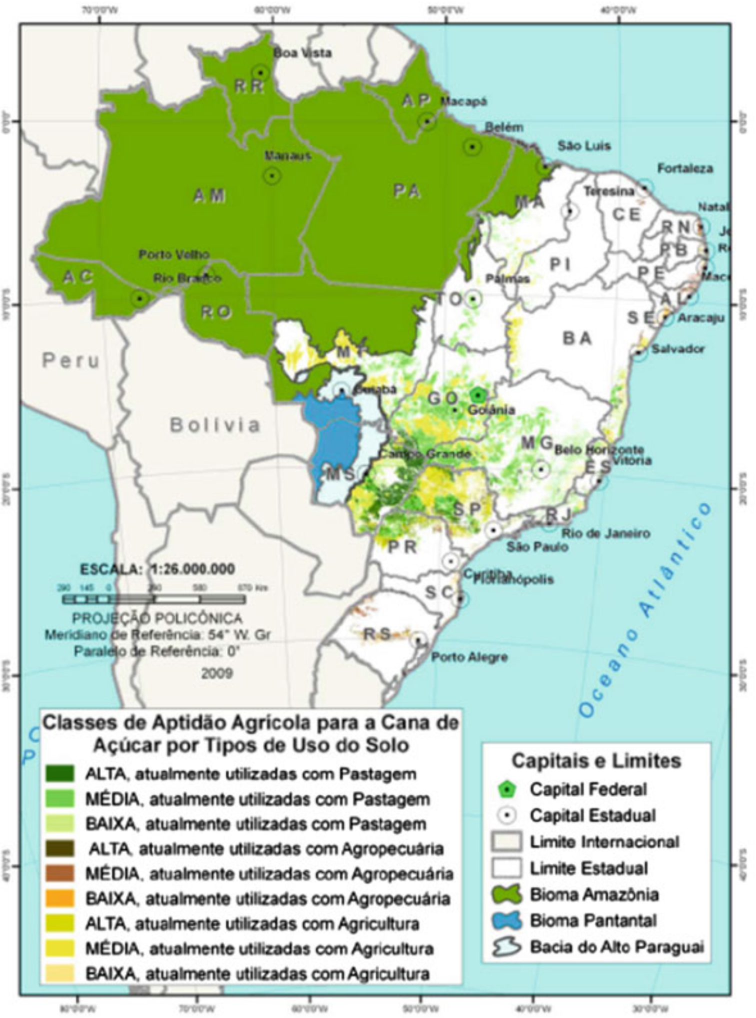
Satolo and Bacchi (2013) evaluated the effects of the expansion of the sugarcane sector on the municipal per capita GDP in São Paulo State. The results from a dynamic spatial panel indicated a positive impact on per capita GDP.

Moraes (2007) and Oliveira (2009) showed that sugarcane production results in higher wages than other crops, a greater level of formal relations (meaning legal protections) and a lower presence of child labor. Sugarcane is a crop with a greater reliance on the external market and a larger production scale, so labor relations tend to be more formalized and in line with legislation.

Sallum (2007), Moraes and Pessini (2004), and Moraes (2009, 2011a) analyzed the institutional and organizational environment of the labor market in the sugarcane industry and observed that there are clear and specific rules governing the labor market. The authors also demonstrated that employer associations and labor unions within the state of São Paulo were strong and highly active and engaged in wage negotiations for the sugarcane workers at the beginning of each harvest season.

2.4.3 Planning Land Use for Bioenergy in Brazil

The prospects of a rapid expansion of the sugarcane sector for the production of bioenergy intended for export has had a major impact on land-use planning in Brazil, such as the Brazilian Land Use Model (BLUM) (Nassar et al. 2009), the Agro-Ecological Zoning of Sugarcane, which was prepared by the Ministry of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Capital Federal
Capital Estadual
Limite Internacional
Limite Estadual
Bioma Amazônia
Bioma Pantantal
Bacia do Alto Paraguai

Fig. 2.9 Sugarcane agro-ecological zoning in Brazil (MMA 2009) http://www.cnps.embrapa.br/zoneamento_cana_de_acucar/ZonCana.pdf

Environment (MMA) (Fig. 2.9), the Agro-environmental Zoning for the cultivation of sugarcane, which was released on 18/09/2008 by the government of the State of São Paulo (Fig. 2.10) and based on the work of the BIOTA FAPESP, and the IAC work coordinated by Orivaldo Brunini in 2008, which resulted in the publishing of an agro-climatic suitability map for the state of São Paulo.

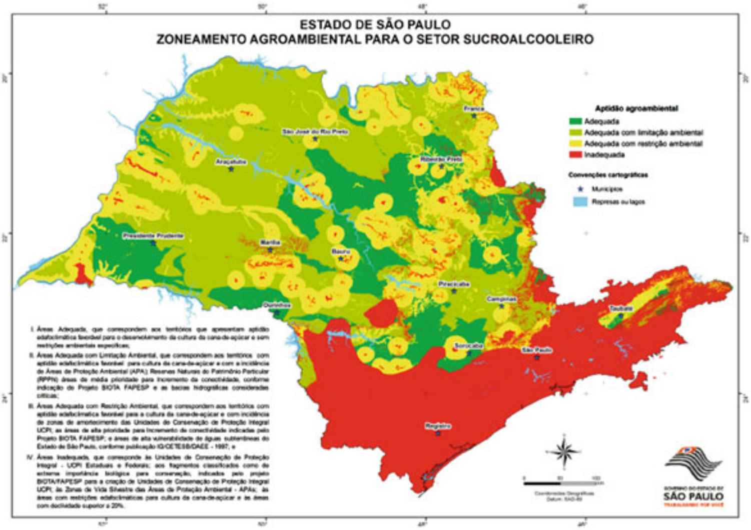

Fig. 2.10 Science-based sugarcane agroenvironmental zoning in São Paulo State http://www.ambiente.sp.gov.br/etanolverde/zoneamento-agroambiental/

2.4.4 *The R&D Contribution of the Sugar and Ethanol Private Sector*

The sugar and ethanol private sector has contributed substantially to consolidating the industry. In agriculture, contributions have been made to research on new varieties and on planting techniques such as the "plene" planting system, which was developed by Syngenta (http://www.syngenta.com/COUNTRY/BR/PT/PRODUTOSEMARCAS/PLENE/Pages/Tecnologia-plene.aspx). (Several industries have introduced harvesters (e.g., John Deere, Case, Valtra, Santal) and Jacto is developing a new concept (ETC) with CTBE (http://www.bioetanol.org.br/noticias/detalhe.php?ID=NDY2).

The New Holland/CTC partnership on raw sugarcane harvesting has developed a system that simultaneously harvests sugarcane and straw and cleans the straw before industrial use (http://www.bioetanol.org.br/noticias/detalhe.php?ID=NDY2).

Brazilian industry has also conducted important research on sugarcane ethanol. Dedini researched the integration of ethanol and biodiesel production and the organosolv process of hydrolysis of bagasse, known as Dedini Rapid Hydrolysis (DHR) (Dedini 2008). Dedini and Fermentec developed a process for reducing amounts of vinasse (http://www.slideshare.net/tabVlae/dedini-fermentec-vinasse-concentration). Dedini also introduced environmentally sustainable solutions designed to reduce water consumption in the process of ethanol production (BIO-WATER) and recycle solid and liquid waste for use as a fertilizer (BIOFOM).

Additional innovations were developed by Braskem, who produced green plastics (polyethylene) using ethanol as the raw material (http://www.braskem.com.br/site.aspx/plastic-green).

In the recent years, significant efforts in increasing ethanol production have been made by the private sector in conjunction with federal and state agencies, such as the GranBio project in Alagoas, Brazil where an ethanol plant is being built and is expected to start operations in 2014 (http://www.novacana.com/n/etanol/2-geracao-celulose/graalbio-preve-usinas-etanol-2g-210313/%23).

2.4.5 Fostering Bioenergy Research in Brazil

Research funding in Brazil is comprised of federal, state, and private initiatives. In building the Brazilian research system, public agencies have been instrumental in improving the quality of research and consolidating graduate programs. Public agencies have made considerable efforts in stimulating businesses to fund research programs, supporting innovative R&D for small businesses, and establishing partnerships for jointly funding research with medium and large companies.

Both the National Research Council—CNPq, which promotes research in Brazil, and the National Fund for Research and Projects—FINEP, which is dedicated to supporting projects with the participation of industry, have been active in financing bioenergy research since the beginning of Proálcool. CNPq played a key role in the early stages of the Proálcool program when it published the book “Rating the technological ethyl alcohol” (Anciães 1978), which was a benchmark in the field of ethanol production. CNPq also acted decisively in offering scholarships to graduates within and outside Brazil at a time when national programs were not yet fully developed.

In the latter half of the 1990s, the federal government created “sectorial funds” (Pacheco 2007). CT-Energ (http://www.mct.gov.br/index.php/content/view/1410/CT___Energ.html) was designed to stimulate energy research and innovation in Brazil and addressed all technical aspects of energy except oil, which had its own specific fund, CT-Petro. Coordinated by ANEEL and ANP together with energy utility companies, funds were raised for R&D and energy efficiency. Bioenergy research to promote innovation that results in better yields and more reliable services has benefited from these resources. However, much more would be gained if there was greater integration of resources, for example, especially in overcoming difficulties related to bioelectricity.

The State of São Paulo Research Funding Agency—FAPESP has contributed considerable resources to bioenergy research (FAPESP 2007). In 1998, the SUCEST project, funded by FAPESP as part of its Genome Program, initiated the sequencing of sugarcane-expressed sequence tags (ESTs). Sequencing the giant genome of sugarcane, where one gene is represented by an average of 10 alleles, is a major challenge. At the time, collections of ESTs represented as a fast alternative

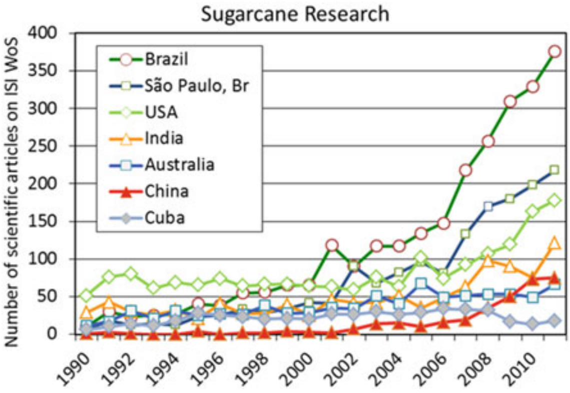

Fig. 2.11 Number of scientific articles on sugarcane cited at ISI WoS for main sugar-producing countries (*Source* Brito 2012)

for the initial characterization of a genome. SUCEST significantly contributed to the identification of genes associated with agronomic traits of interest. Approximately, 43,000 genes were identified (Vettore et al. 2003). This initiative was instrumental in the formation of a network of genome researchers in Brazil and placed the country in the lead of sugarcane-indexed international publications (Fig. 2.11). A survey of research on sugarcane and ethanol funded by FAPESP in recent years has been published in the book "Brazil world leader in knowledge and technology of sugarcane ethanol."

2.4.5.1 Scientific Publications in Sugarcane in Brazil

In Brazil, the Institute of Sugar and Alcohol, created in the 1930s, provided a major contribution to the study of bioenergy by publishing the magazine *Brasil Açucareiro* and *Anuário Açucareiro*, which was a yearbook-type of publication that was started in 1935 and discontinued in 1975. The Society of Technical and Sugar and Ethanol Producers of Brazil—STAB currently represents the only scientific magazine in the country in the sugar-ethanol sector. An inventory of publications held by Vian and Corrente (2007) allows a better understanding of how the industry disseminates its knowledge.

2.4.5.2 Scientific Publications in Sugarcane in Indexed Journals Highlighting the Evolution of Research in Brazil and the State of São Paulo

The SUCEST project was succeeded by two initiatives led by researchers at USP and UNICAMP and a "spin-off" biotechnology company. The SUCEST-FUN project (http://sucest-fun.org), which was started in 2003, focused on the identification of genes associated with agronomic traits of interest (such as yield, tolerance to biotic and abiotic stresses, mineral nutrition, sugar content, and responses to climate change). The project was based at the Institute of Chemistry, USP, and was a collaboration of groups from USP, UNICAMP, UFSCar, CTC, IAC, UFRJ, UFPE, UFRPE, UFAL, and RIDESA. Genes associated with sucrose content and drought resistance have been patented, and transgenic plants were developed that should contribute to the improvement of sugarcane. Concurrently, a project based at CBMEG, UNICAMP, developed molecular markers, genetic-statistical tools, and a functional genetic map for breeding progenies of the CTC, IAC, and RIDESA programs. These initiatives allowed the development of molecular tools that promise to accelerate the release of new cultivars by classical breeding programs (Cantarella et al. 2012).

Alellyx was found in February 2002, by a group of molecular biologists and bioinformaticians involved in the SUCEST project or the FAPESP Genome Program. Set in Campinas, Alellyx operated in partnership with CanaVialis, which was found in 2003, and whose focus was sugarcane breeding. Together, Allelyx and CanaVialis represented one of the most modern sugarcane breeding programs in the world and had an important influence on the FAPESP Genome Program. After the initial phase of venture capital investments by Votorantim New Business, both companies were acquired by Monsanto in what was one of the biggest purchases of a start-up company in Brazil at the time.

In 2008, FAPESP created the FAPESP Bioenergy Research Program BIOEN (http://bioenfapesp.org). BIOEN is organized in five divisions: Biomass, Biofuel Technologies, Biorefineries, Engines, and Sustainability and Impacts. FAPESP establishes partnerships with national and international funding agencies and businesses in its efforts to articulate and integrate research initiatives. CNPq resources, for instance, were mobilized under Pronex and INCT joint grants. The private sector is also represented with BIOEN agreements that involve public research institutions and companies such as Braskem, Dedini, Oxiteno, Microsoft Research, ETH, Boeing, BP, PSA, BE-Basic, and Vale, all of which share human, material, and financial resources. In 2013, the program had grown to more than 400 researchers in over 20 countries. Considering its size, broad research spectrum and the depth of its goals, BIOEN can be considered as one of the most important bioenergy research programs in the world. BIOEN was built on a solid base of exploratory academic research that is generating new knowledge and highly qualified experts, which are essential for enhancing the industry's ability to run on ethanol technologies and increasing internal and external competitiveness.

A strategically important FAPESP project was the Project for Public Policy Research on Ethanol (PPP Ethanol), developed in partnership with APTA (www.apta.sp.gov.br/cana). PPP Ethanol promoted a broad discussion of the entire ethanol production chain from sugarcane, with researchers from academia and the private sector. This research produced a technology roadmap for the sector and resulted in the publication of the book "Bioethanol from Sugarcane: research & development productivity and sustainability" (Cortez-Coord. 2010).

2.4.6 New Frontier Research on Sugarcane Bioenergy

2.4.6.1 Breeding, Molecular Biology, Genomics, and GMOs

In 2009, BIOEN catalyzed a series of discussions on biotechnological paths for the improvement of sugarcane, including the development of new sugarcane varieties with increased yield, tolerance to stress (especially drought), and adaptations to the soil and climate conditions of areas where sugarcane expansion is taking place (mid-west, south, and north east) (Hotta et al. 2010). Defined research priorities included (1) obtaining the sequence of a reference genome of sugarcane (2) developing molecular markers and genetic maps to assist breeding programs in the choice of parents and progenies (3) understanding the physiological processes underlining the partition of carbon, photosynthesis, and use of water (4) discovering genes and functional genomics for identifying genes of interest, and (5) researching the stable production of transgenic plants. Challenges and bottlenecks in breeding were recognized as well as the role of high-performance technologies in overcoming breeding issues.

Improving yield and resilience of sugarcane varieties can be achieved by integrating agronomic practices, adequate management practices, traditional breeding and molecular-assisted breeding, and development of transgenic plants. The discovery of genes associated with agronomical and physiological traits will provide the necessary knowledge for the development of cultivars dedicated to the production of bioenergy (energy cane) or to be used as biofactories.

It is expected that the amount of information regarding sugarcane will increase exponentially in the coming years in response to research incentives. The development of integrated databases, such as the SUCEST-FUN Database (http://sucest-fun.org) is essential for the optimal use of research results. In particular, collecting large amounts of sequence data will require the implementation of bioinformatics and databases for information management. This demand will be similar in systems biology projects designed for an integrated understanding of the various aspects of plant growth and their adaptive development to different environments. Project data management will be absolutely crucial for the integration of heterogeneous data coming from different methodologies and groups.

2.4.6.2 Second-Generation Technologies

Lignocellulosic Ethanol (hydrolysis)

Hydrolysis research in Brazil began with José Carlos Campana Gerez, Institute of Chemistry, UNICAMP, in the late 1970s with studies on acid hydrolysis. These works led to the installation of a pilot plant on the UNICAMP campus, but the project was discontinued in the early 1980s because of a lack of resources. However, the process resulted in patent #PI8203026-0 (1982).

A 1979 initiative of the federal government saw the passage of Law No. 6.768 that established the company COALBRA—Coke and Alcohol Wood S/A, which was based on technology of Russian origin and designed to convert wood into methanol by acid hydrolysis. This project was coordinated by Sérgio Motta, who acquired a full-scale industrial unit that was installed in Minas Gerais, near Uberlândia, but was discontinued because of technical difficulties and a lack of funding. At the beginning of the 1980s, CESP (Companhia Energética do Estado de São Paulo) installed a pilot plant to gasify wood and produce methanol from synthesis gas, which was also discontinued.

Research on cellulosic ethanol production started again in the mid-1990s with studies by Dedini in partnership with the CTC and FAPESP and coordinated by Carlos Eduardo Vaz Rossell. The research, based on the organosolv pretreatment of bagasse, was used in a demonstration plant installed at São Luiz Mill in Pirassununga, SP. The plant had the capacity to produce 5000 L of ethanol/day, taking advantage of the synergy of an integrated process in the first-generation. Because of technical problems regarding the sugarcane bagasse supply, the production of inhibitory compounds for fermentation and a viable use for the fraction of lignin, it became clear that additional research was required at a smaller scale. However, the studies indicated important technical challenges that helped to drive future studies in the area.

In 2005, the Ministry of Science, Technology & Innovation- MCTI, created the Bioethanol Network, which was coordinated by Rogério Cezar de Cerqueira Leite, UNICAMP. The network's activities involved several universities and research institutions (such as CTC) and attempted to identify necessary skills and contribute to the development of a technology to produce cellulosic ethanol in Brazil (http://cenbio.iee.usp.br/projetos/bioetanol.htm). After 3 years of intense work, the Bioethanol Network program was able to identify skills as well as scientific and technological barriers and served as a foundation for the creation of the hydrolysis program at CTBE (National Laboratory of Science and Technology of Bioethanol). The hydrolysis program at CTBE is coordinated by Carlos Eduardo Vaz Rossell and aims to make improvements in the four basic areas of enzymatic hydrolysis: pretreatment, enzymes, hydrolysis, and fermentation. Facilities were installed at the CTBE for conducting experiments at laboratory scale and pilot plant scale (up to 500 L). The pilot plant is a flexible unit, and the cellulosic ethanol conceptual process is designed to make use of the biorefinery concept, which may introduce many potential product options in addition to bioethanol (http://www.bioetanol.org.br/).

CENPES/Petrobras is also developing a program to research cellulosic ethanol, especially in the area of enzyme production, in association with universities and domestic and foreign companies. Dedini has also worked with several companies in search of robust and economically competitive enzymatic hydrolysis processes. Other groups have also emphasized research work in the area of enzymatic hydrolysis, such as the CTC and Luiz Ramos at UFPR.

Considering the worldwide efforts in hydrolysis, it is now understood that the problem is quite complex and offers an opportunity to bring together more basic research, such as understanding the deconstruction of the cane fiber, and technological challenges, such as creating efficient processes for the production of enzymes and obtaining enzymes robust enough to operate in an industrial environment at lower prices. Given the highly favorable characteristics of fiber and the availability of utilities, the 1G plant environment is considered very suitable for coupling a 2G plant. In addition, ethanol fuel hydrolysis technology will allow the plants to make use of the biorefinery concept to produce high-value molecules, such as polymers, and develop innovative products.

The BNDES PAISS Program to Promote Second-Generation Ethanol

The PAISS is a joint initiative of the BNDES and FINEP, which are a selection of business plans and development projects that include the development, production, and commercialization of new technologies intended for the industrial processing of biomass derived from sugarcane. The purpose of PAISS is to organize requests for financial assistance under the two institutions to allow greater coordination of actions for development and better integration of available financial support instruments http://www.bndes.gov.br/SiteBNDES/bndes/bndes_pt/Areas_de_Atuacao/Inovacao/paiss/.

The PAISS program is prepared to invest R$1 billion (nearly US$400 million) to install pilot plants and demonstrate innovative technologies in this area. The company GraanBio (GranBio) is planning a demonstration unit for second-generation bioethanol from sugarcane bagasse that should be operational by the first semester of 2014. The mill will have the capacity to produce 82 million liters/year, and it will use innovative solvent-free processes in the pretreatment step. The initiative will offer an opportunity to evaluate the technology and obtain process data and information for the design of large-scale units.

Thermoconversion Technologies: Torrefaction, Gasification, Pyrolysis, and Combustion

Experimental work on the thermoconversion of biomass (torrefaction, pyrolysis, gasification, and combustion) was started at the Institute for Technological Research (IPT) in São Paulo in the 1970s when the combustion laboratory was created.

Two groups stand out in this area: Carlos Luengo at IFGW-UNICAMP, who conducted basic research into the processes of thermal conversion of biomass pyrolysis and roasting, and Saul D'Avila at FEQ-UNICAMP, who researched and formed many frames in gasification and pyrolysis of biomass. Concurrently, CIETEC of Rio Grande do Sul was conducting research in the area of thermal biomass conversion. The CTC in the 1990s led first phase of the GEF project with the support from the World Bank to conduct research and gather information about the gasification of straw and bagasse. This project was designed for the eventual construction of an advanced gasification pilot plant, but was halted because of funding problems. CHESF, with the participation of Shell and support from GEF (Global Environmental Facility), attempted to complete the second phase with a focus on gasification of eucalyptus wood, but because of administrative and financial difficulties, the second phase of the project was never completed. The IPT currently continues to work in this area in collaboration with Swedish industries that research pyrolysis charcoal. The work performed by the UFMG (Maria Emilia Rezende) resulted in the creation of the company Biocarbo, although it is not involved in managing sugarcane biomass. As a result of the efforts of Saul D'Avila, José Cláudio Moura and Themistocles Rocha, the Termoquip company was started in the region of Campinas and produces biomass gasifiers, including Petrobras, and has been instrumental in the creation of various reactors used for research at UNICAMP (FEQ, FEM and AEC) and UNIFEI. A spin-off company called Bioware produces thermal conversion technology for sugarcane and produces products such as bio-oil, acids and pyrolytic carbon. A lab-scale pyrolysis and gasification unit was designed and constructed specifically to process sugarcane bagasse and straw and is currently in operation with the focus of obtaining kinetic data for the reaction and gathering useful information for process scale-up. The project is coordinated by Rubens Maciel Filho at FEQ/UNICAMP.

2.4.7 New Bioenergy Research Centers and a Graduate Program in Bioenergy in Brazil

The new generation of bioenergy research centers in Brazil linked to the resurgence of ethanol have been motivated by events of this century such as the electricity "blackout" in 2002, production of flex-fuel cars, and interest by the United States in second-generation ethanol research, which is considered more sustainable than the first-generation when compared to ethanol from corn and other cereals.

In the early 1990s, he National Reference Center for Biomass-CENBIO was created to develop research activities in conjunction with universities and companies in the area of bioenergy. CENBIO has made important contributions to government policies at the state level, such as studies conducted by the State Committee for Bioenergy and coordinated by José Goldemberg (Goldemberg et al. 2008).

In 2005, a project coordinated by Rogério Cerqueira Leite was begun that performs a series of studies with the Center for Strategic Studies and Management in Science, Technology, and Innovation—CGEE to study issues involved with the possibility of replacing 10 % of all gasoline consumed worldwide with ethanol from sugar cane by 2025, which would constitute an increase of approximately 10 times the ethanol currently produced in a season (Leite 2009 and Leite et al. 2009). This study allowed Brazil to better understand the importance of producing high-level research toward the sustainable use of whole-sugarcane resources. Created officially in 2008, the National Laboratory of Science and Technology of Bioethanol—CTBE at the CNPEM in Campinas, SP began 5 research programs covering basic research, mechanization, minimum impact agriculture, hydrolysis, and virtual biorefinery sustainability.

The federal government created the Agroenergy Embrapa Center in 2006 in Brasilia research issues related to biodiesel, ethanol, and the energetic use of agricultural and forest residues.

Petrobras Biofuels has promoted the engagement of CENPES in the research of biofuels and is primarily studying second-generation ethanol.

The reorganization of IAC sugarcane research that was started in the 1990s led to the creation of the Centro Cana IAC/APTA in Ribeirão Preto, where laboratories were installed to research plant breeding, agricultural entomology, biotechnology, agribusiness technology, and management of sugarcane varieties. The research center currently houses a public collection of germplasm of sugarcane.

The creation of the State of São Paulo Bioenergy Research Center was also important. This center is a consortium of three state universities in São Paulo (USP, UNICAMP and UNESP) and FAPESP and will have a research budget of $75 million. The infrastructure is funded by the government of the State of São Paulo, and the universities are already hiring professors. FAPESP’s role is to fund high-quality research in bioenergy.

A new Ph.D. program in bioenergy is being jointly implemented by USP, UNICAMP, and UNESP in an attempt to create highly qualified human resources. This initiative demonstrates the commitment of these universities in promoting long-term research and innovation in the field of bioenergy in Brazil. The new program will have a strong international orientation and will collaborate with the best universities and research centers around the world http://agencia.fapesp.br/en/17301.

2.5 The Use of Vegetable Oils for Biodiesel Production

2.5.1 Brazilian Biodiesel Research from Vegetable Oils

When Proálcool was first begun, the federal government also proposed “Proóleo,” a national program based on the production of vegetable oil fuel to replace diesel.

Unlike the sugar and alcohol sector, which had already organized, Proóleo did not have a sector or culture to lean on in 1970s. At the time, soy was a nascent culture in Brazil, and other oilseeds, including palm, were not produced commercially or at scale. Fernando Homem de Melo and Eduardo Giannetti da Fonseca from USP, writing in “Proálcool, Energy and Transports,” calculated land requirements for different cultures of oil crops (Melo and Fonseca 1981).

In 1969, Leopold Hartman at FEA—UNICAMP published an important article on the transesterification of vegetable oils and created the Laboratory of Oils and

Fats with the support of GTZ (Informativo SBCTA 2005). The first patent for biodiesel and aviation jet fuel in Brazil (PI8007957) is credited to Expedito Parente in 1980. Ulf Schuchardt from IQ—UNICAMP patented the use of vegetable oils for fuel purposes (#PI 8302366-6) and published "Continuous reactor with organic heterogenized catalysts for transesterification of vegetable oils" in 1982 and "Process for the preparation of esters with organic catalysts and method of rapid determination of the composition of oils and fats" in 1983.

Although there was available technology to produce biodiesel in Brazil, problems remained concerning the raw material. Replacing diesel fuel would require the cultivation of an energy crop for oil, as sugarcane was for ethanol. Although the cultivation of palm is considered equivalent to sugarcane, an agricultural sector did not exist that was sufficiently organized to realize this potential. However, recent information indicates that the palm crop is expanding in the State of Pará.

Biodiesel is popular in Europe, where it is produced with rapeseed, and was initially considered as an option in Brazil that could meet social goals and alleviate dependence on diesel. On January 13, 2005, the federal government enacted Law No. 11.097, which created the National Program for Production and Use of Biodiesel—PNPB. Despite initially suggesting the production of biodiesel in family units and making use of transesterification of ethanol, more than 80 % of biodiesel in Brazil is currently produced using soybeans and methanol because of the absence of other oil crops on the scale of soybeans and the technical difficulties in the transesterification of ethanol.

If Brazil invests in oil crops with energy potential such as oil palm and produces the equivalent of the biodiesel yield in Malaysia and Indonesia, which is approximately 5,000 L of oil/ha year, then a sustainable program to replace diesel with biodiesel can be developed, an example of which has been developed in Colombia.

2.5.2 *Other Routes for Biodiesel Production*

The sector of renewable chemicals is also considering of producing new compounds and biofuels via biological routes, which is called synthetic biology. Synthetic biology is engaged in the construction of new components and biological systems or redesigning natural systems using evolutionary processes. These artificial systems can perform new tasks, such as the production of plastics, biokerosene and bio-gasoline. A major initiative is underway by Amyris, a California company that opened a subsidiary in Brazil for the production of new biofuels such as biodiesel and aviation fuel from sugarcane sucrose (Amyris 2008). Amyris's initial goal was to develop technology that allowed the production of an antimalarial drug, artemisinin, by microorganisms. The platform is being applied industrially to the development of yeast with the ability to produce gasoline and kerosene and to the scheduling of production processes for farnesenes. This approach must be improved to match production requirements and market prices, especially with respect to bio-kerosene.

The production of biodiesel from algae should also be mentioned, particularly for its ability to minimize land use for biofuels. This technology aims to produce third generation biofuels, which are produced from the use of CO_2.

A group led by Franco and Maciel at FEQ-UNICAMP and Ana Teresa Lombardi (UFSCar) have been researching the use of algae to produce biodiesel; however, production of biodiesel from algae is still somewhat advanced in Brazil, although it deserves attention, especially because it is so innovative in that it does not require land and makes use of CO_2. Numerous lab-scale studies are evaluating the use of microalgae as a lipids feedstock for biodiesel, and many interesting options are under consideration, especially those that integrate CO_2 from ethanol mill fermentation to increase microalgae growth (research project funding by FAPESP 2008/57873-8).

2.6 Future Perspectives of Biofuels for Aviation in Brazil

In October 2011, Boeing, Embraer and FAPESP formally agreed to investigate how Brazil could contribute to the production of sustainable biofuels for aviation in an attempt to reduce CO_2 emissions. The result was Sustainable Aviation Biofuels Brazil, a national assessment of the technological, economic and sustainability challenges, and opportunities associated with the development and commercialization of sustainable aviation biofuel in Brazil.

Multiple possible pathways to produce biofuels for aviation were identified during the project. Certification requirements for use in commercial aviation are established internationally according to ASTM D7566, which contains one special annex for each approved alternative jet fuel production process. Figure 2.12 presents an overview of all identified pathways pertinent to Brazil, including the denomination and status of the ASTM approval process. As depicted, two of the final jet fuel production processes are already approved (green boxes in Fig. 2.12), and several others are still under analysis in ASTM's Emerging Fuels Committee.

The project concludes that Brazil has exceptional conditions to develop and produce sustainable biofuels for aviation. However, additional research is required to develop the identified pathways and additional effort is required to improve the transportation infrastructure to lower raw material costs. More information can be found here: http://www.fapesp.br/publicacoes/flightpath-to-aviation-biofuels-in-brazil-action-plan.pdf.

Recently, the Brazilian National Agency for Oil, Natural Gas and Biofuels-ANP approved resolutions for biofuels for aviation in Brazil (http://www.petronoticias.com.br/archives/31531).

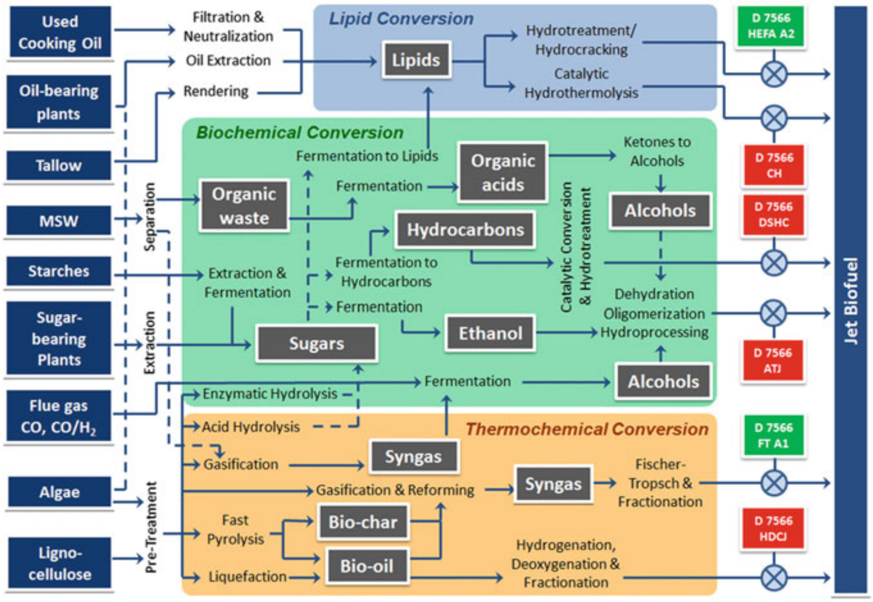

Fig. 2.12 Identified pathways for the production of sustainable jet biofuel in Brazil [*Note HEFA* Hydroprocessed Esters and Fatty Acids; *CH* Catalytic Hydrothermolysis; *DSHC* Direct fermentation of Sugars to Hydrocarbons; *ATJ* Alcohol to Jet; *FT* Fischer-Tropsch hydroprocessed-synthesized paraffinic kerosene; *HDCJ* Hydrotreated Depolymerized Cellulosic to Jet] (Boeing et al. 2013)

2.7 Conclusions

Brazil has a prosperous future in the field of bioenergy. The participation of sugarcane in the Brazilian energy matrix has grown 1 % per year since 2002, reaching 19 % in 2010. Although the potential is much larger, not only for sugarcane but for eucalyptus, palm tree, and innumerous other crops, the country has already built a significant history in the bioenergy area. However, much more can be done, particularly in adding combined value to products and utilizing concepts that produce sustainable solutions to improve the industry in the new agricultural frontiers of Brazil.

The long-term role played by the Brazilian government in promoting biofuels is considered as a key factor to success, particularly with sugarcane ethanol. Government-funded research agencies have played a strategic role in consolidating knowledge and human capacity to maintain leadership in the bioenergy sector.

However, investments in research and development of human resources in the area of bioenergy must also grow proportionately, particularly in the private sector. With new research centers, graduate programs have the potential to contribute to increasing competence at all stages of bioenergy development.

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